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PATENT SPECIFICATION

(11) 1 214 852

DRAWINGS ATTACHED

(21) Application No. 49407/67 (22) Filed 5 Jan. 1968
(45) Complete Specification published 9 Dec. 1970
(51) International Classification F 02 f 3/08
(52) Index at acceptance
F1B 2J4A 2J5
B3F 16A123 16B2C1
F2T 37A2

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(54) IMPROVEMENTS IN OR RELATING TO PISTONS FOR INTERNAL COMBUSTION ENGINES

(71) We, INTERNATIONAL HARVESTER COMPANY of 401 North Michigan Avenue, Chicago, Illinois 60611, United States of America, a corporation constituted under the laws of the State of Delaware, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a piston for use in an internal combustion engine and, more particularly, but not exclusively, to a piston of the open chamber type, that is to say a piston having a combustion chamber formed in the piston head.

Internal combustion engine pistons are subjected to unusual stress systems and unique environmental conditions in use. Since the stress system is affected by thermal gradients and heat load cyclic conditions, the overall system becomes very complex. In certain types of piston designs such as open chamber pistons wherein a combustion chamber is formed in the piston head, thin lips and complex geometrical configurations contribute to the stress field complexity. Mechanisms of piston cracking may be affected by the properties of piston materials in regard to elevated temperature fatigue, thermal, shock, thermal stress fatigue and thermal fatigue.

The present invention broadly provides an annular insert which defines an opening in the head of a piston and which is prestressed in such a manner as to overcome the stresses which will be induced in it during use, and a method of making a piston which includes such an annular insert constituting the relatively thin lip areas which are subjected to high stresses during the piston operation.

In order to appreciate fully the merits and novelty of the piston construction and method of making the same which form the basis of the present invention, it is thought necessary to briefly review the mechanism by which material failures may occur in piston designs presently being used. The present invention is primarily concerned with the elimination of the type of failure commonly referred to or called "thermal cracking". As will be understood from what has already been said, this terminology is somewhat naive as the conditions causing cracking may be quite complex.

When material separation occurs, it is due to stresses of a given nature being greater than the strengths of the same variety. In internal combustion engine pistons of the open chamber type wherein a cavity is provided in the head of the piston which cavity opens into the piston face, the fractures in the piston face invariably emanate from the relatively thin lip defining the chamber opening and extend radially outwardly on the face of the piston. It has been found that, when a stress is anticipated in a given direction in a member, a preload stress applied to the member which is opposite in sign to the anticipated stress will result in an increase in durability of the member. However, before the problem of cracking of a piston head or face can be solved by utilising this principle and by incorporating a counteracting stress system in the piston, it is necessary to know the nature and application of the stresses generated in the piston when in use. The present Applicants have devoted considerable thought to this question, and they have concluded that at least the following stress generating systems are possible:

1. *Static Thermal Gradients*

Any part which is subjected to a heat source on one side and a coolant on the other has generated in it a thermal gradient. If this gradient is steep enough, stresses of significant magnitude can be developed. Under steady strain conditions the significant

characteristics of the materials to resist crack formation are stress-rupture and creep characteristics. This condition is not particularly significant in Diesel pistons; however, the principles involved in the present invention might well be applicable and of importance in other applications.

2. *Dynamic Thermal Gradients*

When a thermal gradient is caused to change by modification of the heat and cooling systems, cyclic stresses are induced.

(a) As an example, if a particular part of cylindrical shape is brought to a given elevated temperature which is allowed to become uniform throughout, then subsequently quenched so that the surface is brought down in temperature rapidly in relation to the interior, transient circumferential tensile stress is generated at the part surface and a balancing compressive stress in the interior.

(b) In reverse, when a part of cylindrical cross section is heated very rapidly from the essentially cold condition a reverse thermal gradient is imposed and compressive circumferential surface stresses are generated which are balanced by tensile stresses in the interior.

When either of the above described thermal-cycles is repeated in a large number of cycles and the elastic strains generated are of a sufficient magnitude, thermally induced stress fatigue, referred to above as thermal stress fatigue, will result.

3. *Cyclic Plastic Strain*

When the thermal gradients described in No. 2 above are severe enough to cause appreciable permanent set in the part in a single thermal stress cycle, failure will occur in a short number of cycles and possibly even one. This is referred to above as thermal shock. From the foregoing it is believed understandable that the properties of materials used for making pistons, such as co-efficient of conductivity, co-efficient of expansion, hot strength and elastic modulus are important when thermal cycling of the piston is involved.

With the possibility of the aforementioned stress systems being generated in the piston under elevated temperature conditions as might be present in a Diesel engine piston used in a motor vehicle, the present invention has for its object a substantial reduction in the effectiveness of such stress-generating systems to influence the durability and operating life of the piston adversely, and, as already indicated, there is provided in accordance with the present invention a piston, the head of which includes an annular insert forming the thin lip area or critical area of high stress concentration, which insert is prestressed in a particular manner to increase the durability of the piston under normal operating conditions. In addition to the thermally-induced stresses, the piston is also subjected to stresses caused by the explosions in the combustion chamber during operation of the engine. It has been found that, when a stress is anticipated in a given direction in a member, a preload stress applied to the member which is opposite in sign to the anticipated stress will result in an increase in durability of the member. The latter stresses imparted to the lip area by the combustion explosion forces in an open chamber type piston are generally circumferential and tensile in nature and, therefore, the insert for the piston is prestressed in compression, a direction opposite the stresses caused by such combustion explosions to increase the durability of the piston.

More specifically in accordance with the present invention there is provided a piston for an internal combustion engine comprising a piston head having a top surface, a skirt depending from the piston head, and a combustion chamber formed in the top surface of the piston head by a surface portion of a recess in the top surface of the piston head and by an annular insert, a lip of which defines an external opening into the combustion chamber, the annular insert being prestressed so as to be in a state of compression at ambient temperature by the action of an annular ring which encircles and engages a surface portion of the annular insert.

A piston of the open chamber type, therefore, has an insert which defines the upper portion of the combustion chamber and forms the annular lip of the combustion chamber at the top surface of the piston head.

The present invention also relates to the manufacture of a piston including an annular insert having the characteristics mentioned. According to this aspect, therefore, there is provided a method of forming a piston having an open chamber in its top surface comprising the steps of forming an insert which defines an opening and which has an internal lip, subjecting the insert to forces which put the insert into a state of compression, and, whilst the insert is maintained in the said state of compression, casting a piston onto the insert, the piston having its head recessed so that the open chamber is formed in part by the insert and in part by the cast piston.

Preferably the insert is placed in a state of compression by an annular ring which is placed around the annular insert before the piston is cast. According to another aspect of the present invention therefore, there is provided a method of forming a piston having an open chamber in its top surface comprising the steps of forming an insert which defines an opening and which has an internal lip, placing an annular ring onto the exterior surface of the insert in such manner as to cause the annular ring to prestress the insert

into a state of compression, and casting a piston onto the insert and the annular ring, the piston having its head centrally recessed so that the open chamber is provided in part by the insert and in part by the cast piston.

Conveniently a piston of an open chamber type has a generally spherical chamber opening to the top surface of the piston in which combustion primarily occurs, an annular insert of a suitable high strength of material defining the opening to the chamber, and a compression ring which is heat shrunk onto the annular insert to provide a preload stress. The insert also forms the inwardly extending upper lip of the chamber at the intersection of the chamber with the top surface of the piston. By matching the materials of which the piston proper, the annular insert and the annular compression ring are made as far as the co-efficients of expansion of such materials are concerned, the thermally induced stresses can be reduced to a tolerable level.

It is well known that the co-efficients of expansion of materials of mating parts affect the stress level induced on such mating parts and interfaces. In general, the lower the co-efficient of expansion the better; however, given one of the aforementioned piston parts made of a material with a particular co-efficient of expansion, ideally, taking into consideration the gross temperature gradients caused by variations in thermal conductivity, the co-efficients of expansion of the other piston parts of the piston according to the present invention may be matched to cause very little relative movement and, consequently, to avoid the generation of high stresses.

Preferably the co-efficient of expansion of the material of which the annular ring is made in equal to or greater than the co-efficient of expansion of the material of which the piston head is made. Also the co-efficient of expansion of the material comprising the annular ring is advantageously greater than the co-efficient of expansion of the material comprising the annular insert.

The invention will be further understood from the following detailed description of preferred embodiments thereof, which are made, by way of example, with reference to the accompanying drawings, in which:—

Figure 1 is a vertical cross-sectional view through a piston of the open chamber type having a prestressed insert therein forming the entrance opening of the chamber in the head of the piston;

Figure 2 is a top plan view of the piston of Figure 1 on a reduced scale, and

Figure 3 is a vertical cross-sectional view of an open chamber type piston having a second embodiment of prestressed insert therein.

Referring to the drawings in detail, wherein like reference characters represent like elements throughout the various views, there are shown illustrative embodiments of the present invention. Figures 1 and 2 disclose a piston 10 of the open chamber type for use in an internal combustion engine, such as a Diesel engine, with the piston preferably being formed of a relatively light weight metal, such as aluminum or an aluminum alloy. The piston 10 includes a head 11 and a depending skirt portion 12 containing wrist pin bosses 13 which define wrist pin openings 14 as is conventional in piston design.

Formed in the exterior circumference of the head 11 are a plurality of circumferential grooves 15 adapted to receive piston rings for the sealing of the piston within a cylinder; the uppermost groove 15 being formed in an annular ring 16 of a high strength metal, such as a ferrous alloy, where wear on the piston ring grooves is greatest and the seating of the first piston ring is of importance in preventing compression leakage. The top surface or face 17 of the piston head 11 is formed with a central hemispherical chamber 18 and an annular undercut groove 19.

The upper portion 21 of the chamber is formed within a generally annular insert 22 positioned in the groove 19. The insert 22 is formed of a suitable high strength material, such as a ferrous alloy of the Ni-Resist type ("Ni-Resist" is a Registered Trade Mark) or it may be made of grey cast iron. Preferably the material should have a high co-efficient of thermal conductivity to enhance its ability to dissipate heat and thus substantially reduce the magnitude of local hot spots and the nominal temperature at which the piston operates. The material also should have a relatively high resistance to yield, creep-rupture and fatigue at elevated temperatures. The insert 22 provides an annular internal lip 23 defining the entrance to the chamber and an external and outwardly extending lower lip or flange 24 defines an annular groove or channel thereabove. An annular ring 26 of a material having high strength at normal as well as operating temperatures of the piston and good resistance to tempering is positioned in the channel or groove formed above the flange 24 and surrounds the insert 22. Preferably, the annular ring 26 is made of austenitic or martensitic stainless steel alloys or Ni-Resist type alloys having tailored co-efficients of expansion . The flange 24 has parallel sides and an annularly disposed or inclined outer edge 25 forming an undercut portion for the undercut groove 19 of the piston head 11. From the aforementioned list of preferable materials of which to make the piston proper, insert 22 and ring 26, it will be apprecia-

ted that the ring 26 is made from a material having a co-efficient of expansion equal to or greater than the co-efficient of expansion of the piston material proper and greater than the co-efficient of expansion of the insert material.

Through experimentation and knowledge gained through experience and as pointed out herebefore, indications have shown that when a stress in a given direction is anticipated, a preload stress opposite in sign applied to the system will result in an increase in durability. Here, the lip area 23 of the chamber 18, 21 of the piston 10 because of its geometric configuration and location will be exposed to higher stresses during the operation of the internal combustion engine than any other area or part of the piston. As pointed out hereinbefore, the lip area 23 is subjected to radially outwardly directed pressures caused by the combustion explosions which pressures result in circumferential tensile stresses being generated in the lip area 23. Therefore, in accordance with the invention, the insert 22 is prestressed in compression prior to assembly in the piston 10 by the annular ring 26 to counteract such outwardly directed forces caused by the explosions in the combustion chamber applied on the combustion chamber wall and the induced tensile stresses in the lip area 23 occasioned thereby. It will also be appreciated that the thermally-induced stresses in the area of the annular lip 23 generated when the face of a hot piston when suddenly cooled are circumferential and tensile in nature as pointed out above.

It should also be pointed out that as far as the many factors adversely influencing piston operating life are concerned, the thermally-induced stress system is, by far, more critical and significant than the pressure-induced stress system caused by combustion explosions. Thus, more importantly, the fact that the insert 22 is prestressed in compression enables such thermally-induced stresses to be also counteracted by the prestress system incorporated into the insert 22.

In addition to the prestress system embodied in the piston design of the present invention, additional means are provided for enhancing the life of the piston. The fact that the annular ring 26, insert 22 and the body of the piston are made of different materials which materials have, as stated hereinbefore, different co-efficients of expansion the deleterious effect of the thermally-induced stress system is substantially mitigated as will be pointed out presently. As an example, at wide open throttle, full load engine operating conditions, the piston top temperature is essentially uniform and at a maximum. However, the operating conditions may then be charged, for example by reducing the load on the engine as might occur if the engine containing the piston was utilised to propel a motor vehicle and the motor vehicle should crest the top of a steep grade and begin to coast on the other side. When this occurs, essentially cold air is drawn into the cylinders and the piston top is quenched by the ingested cold air. Under these circumstances, a temperature gradient is produced which can be described by saying that the top surface of the piston is cold being in contact with the coolant (cold air), while the interior mass or mass beneath the piston top is still substantially hot. This is obviously a transient condition. It can be reasoned though that a significant tensile stress can be generated under these conditions in the surface of the piston in direct contact with the cold air. The colder surface material attempting to contract around the hotter interior material will be in tension and the interior in balancing compression. Consequently, in those prior piston designs wherein the insert 22 and annular ring 26 do not exist and such insert and ring are, in effect, integrally formed with and of the same material as the piston body, radially extending cracks emanating from the thin lip 23 at the entrance of the combustion chamber often-time developed in the top surface or face 17 of the piston head 11. With the piston construction described above and embodying the invention, the annular ring 26 is made of material that has a co-efficient of expansion equal to or greater than the co-efficient of expansion of the material of which the piston head 11 is made. Consequently, in the example given above wherein the piston face 17 is suddenly quenched by ingesting cold air into the engine cylinder and a temperature gradient is produced in the piston, detrimental tensile stresses are generated in the "quenched" surfaces of the piston which "quenched" surfaces include the portion of the piston face 17 disposed radially outwardly of the annular ring 26, and the exposed surfaces of the annular ring 26 and the annular insert 22. When the material of the annular ring 26 is deliberately selected to have a co-efficient of expansion greater than the co-efficient of expansion of the piston body material, the surface portion of the piston face 17 radially outwardly from the annular ring 26 reacts to a lesser degree than the exposed surface of the annular ring 26 to such temperature gradient. Thus, as the aluminum or aluminum alloy surface portion of the piston face 17 radially outwardly from the annular ring 26 attempts to contract in the above operating condition used as an example tending to set up detrimental circumferential tensile stresses, the annular ring 26 being made of a material having a relatively greater co-efficient of expansion, will have a higher rate of contrac-

tion and, thus such contraction of the aforementioned annular portion of the piston face 17 has very little effect, if any, on the stress condition present in the area of the lip 23 or the critical area where failure is most likely to occur. In effect, the annular insert 22 and, in particular the critical high stress concentration area of the lip 23 of such insert 22, is isolated from influence of the tensile stresses thermally induced in the annular portion of the piston face 17 disposed radially outwardly of the annular ring 26.

As pointed out hereinbefore, while tensile stress would be present at the piston top surface in general during the aforementioned engine operating conditions, it is somewhat aggravated and concentrated at the piston lip 23. It has been established that the lip 23 constitutes the critical area as far as failure is concerned, and, consequently, the present invention is primarily concerned with the provision of counteracting stress at this location during the " down transient " operating condition, i.e. when the piston top is being cooled from an elevated temperature. It will also be appreciated that inasmuch as the co-efficient of expansion of the annular ring 26 is greater than the co-efficient of expansion of the insert 22 the surface portion of the insert 22 radially inwardly from the annular ring 26 will, accordingly, react to a lesser degree than the exposed surface of the annular ring 26 to such temperature gradient. Thus, the annular ring 26 will contract more rapidly than the internal lip 23 and a compression stress will be generated and since such compression stress generation is occurring at the time the " down transient " is generating a tensile stress, the compressive stress will tend to negate the detrimental tensile stress in the lip 23.

From the foregoing, it will be appreciated that, by prestressing the annular insert 22 in compression and by making the annular ring 26 of material having a co-efficient of expansion greater than the co-efficient of expansion of the material of which the piston proper is made, the thermally-induced stresses as well as the stresses resulting from combustion explosions on the exposed surface of the annular insert 22 and especially the critical high stress concentration area of the annular internal lip 23 are reduced to a tolerable level. It therefore follows that the durability and operating life of the piston is increased tremendously. It is to be understood that a wide variety of materials are available to be utilised for constructing the piston body proper, the annular ring 26 and the annular insert 22. It is merely necessary to select the materials bearing in mind the aforementioned properties required of each of the materials and parts in order to achieve the very desirable prestress and operating stress system in the piston

In the construction of the piston, ring 26 is heat shrunk onto the insert 22 causing an inwardly directed compressive stress to be imparted to the insert 22 at ambient temperature. The piston 10 is then cast around this annular ring 26 and prestressed insert 22 with the flange 24 of the insert 22 forming an interlock with the piston in the groove 19. The insert-to-ring interface, insert-to-piston material interface, and ring-to-piston material interface are all suitably treated in such a manner as to improve metallurgical bonding therebetween and improve heat flow at the junctures. Obviously, the annular ring 16 is properly located in the mould relative to the annular ring 26 and insert 22 prior to casting the piston 10.

After casting, the piston 10 is machined to the accurate size required as shown in Figure 1 and the grooves 15 are machined into the piston head 11 and the annular ring 16. Once the piston rings (not shown) are inserted into the grooves 15, the piston is then ready for use. In view of the preload stress on the insert 22, the lip 23 at the entrance to the chamber 18, 21 will show substantially improved resistance to cracking and increased durability during use.

A second embodiment of insert in a piston 10*a* is shown in Figure 3, the piston having a piston head 11*a* with a face 17*a*, the piston formed with a hemispherical chamber 18*a* and the head with a groove 19*a*. An insert 27 having a chamber portion 28 therein, and defining an internal lip 29 for the chamber is positioned in the groove 19*a*. The insert is provided with a plurality of radial arms 31 integral therewith and integral with an annular ring 32 incorporated within the exterior surface 33 of the piston head 11*a*. A compression ring 34 is heat shrunk onto the outer surface of the insert 27 prior to casting of the piston 10*a* to create a prestress in the insert. Then the insert 27 and integral annular ring 32 and the compression ring 34, previously shrunk onto the insert, are positioned in a suitable mould, and the piston material is injected therein to encompass and flow around the annular ring 32 and radial arms 31 and surround the insert 27 and compression ring 34. The piston surface is then machined and the piston ring grooves 15*a* are machined in the piston head 11*a* and in the annular ring 32.

WHAT WE CLAIM IS:—

1 A piston for an internal combustion engine comprising a piston head having a top surface with an opening therein, the lip of the opening in the top surface of the piston head being constituted by an annular insert located in the piston head, which annular insert is pre-stressed to be in a state of compression.

2. A piston for an internal combustion

engine comprising a piston head having a top surface, a skirt depending from the piston head, and a combustion chamber formed in the top surface of the piston head by a surface portion of a recess in the top surface of the piston head and by an annular insert, a lip of which defines an external opening into the combustion chamber, the annular insert being prestressed so as to be in a state of compression at ambient temperature by the action of an annular ring which encircles and engages a surface portion of the annular insert.

3. A piston according to Claim 2 wherein the co-efficient of expansion of the material comprising the annular ring is greater than the co-efficient of expansion of the material comprising the annular insert.

4. A piston according to Claim 2 or Claim 3 wherein the co-efficient of expansion of the material of which the annular ring is made is greater than the co-efficient of expansion of the material of which the piston head is made.

5. A piston according to any one of Claims 2 to 4 including a second annular ring in the exterior surface of the piston, the said second annular ring having an annular groove therein for receiving a piston ring.

6. A piston according to any one of Claims 2 to 4 further comprising a means for interlocking the piston head and the annular insert.

7. A piston according to Claim 6, in which the interlocking means includes a radial lip at the lower end of the annular insert extending radially outwardly beyond the first-mentioned annular ring, the radial lip having an angularly disposed outer surface for interlocking engagement with a complementary surface in the piston head.

8. A piston according to Claim 6, in which the interlocking means includes a plurality of radial arms integral with the insert, and a second annular ring integral with the said arms and located in the outer circumference of the piston.

9. A piston according to Claim 8, in which the annular ring in the outer circumference of the piston has a piston ring grooved formed therein.

10. A piston for an internal combustion engine constructed substantially as described with reference to either Figures 1 and 2 or Figure 3 of the accompanying drawings.

11. A method of forming a piston having an open chamber in its top surface comprising the steps of forming an insert which defines an opening and which has an internal lip, subjecting the insert to forces which put the insert into a state of compression, and, whilst the insert is maintained in the said state of compression, casting a piston onto the insert, the piston having its head recessed so that the open chamber is formed in part by the insert and in part by the cast piston.

12. A method of forming a piston having an open chamber in its top surface comprising the steps of forming an insert which defines an opening and which has an internal lip, placing an annular ring onto the exterior surface of the insert in such manner as to cause the annular ring to prestress the insert into a state of compression, and casting a piston onto the insert and the annular ring, the piston having its head centrally recessed so that the open chamber is provided in part by the insert and in part by the cast piston.

13 .A method of forming a piston according to Claim 12, wherein the annular ring is made of a material having a co-efficient of expansion greater than the co-efficient of expansion of the material of which the insert is made.

14. A method of forming a piston according to Claim 12 or Claim 13, in which the annular ring is heat shrunk onto the exterior surface of the insert to prestress the insert in compression.

15. A method of forming a piston according to any one of Claims 12 to 14, including the step of forming the insert with a plurality of integral radial arms and an annular ring integral with the said radial arms and positioned to be exposed in the exterior surface of the formed piston.

16. A method of forming a piston according to any one of Claims 11 to 15, including the step of forming spaced piston ring grooves in the exterior surface of the piston.

17. A method for forming a piston for an internal combustion engine substantially as hereinbefore described.

18. A piston for an internal combustion engine formed by a method according to any one of Claims 11 to 17.

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Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1970
Published at the Patent Office, 25 Southampton Buildings, London WC2A 1AY from which copies may be obtained.

1,214,852 COMPLETE SPECIFICATION
1 SHEET
This drawing is a reproduction of the Original on a reduced scale.

FIG. 1.

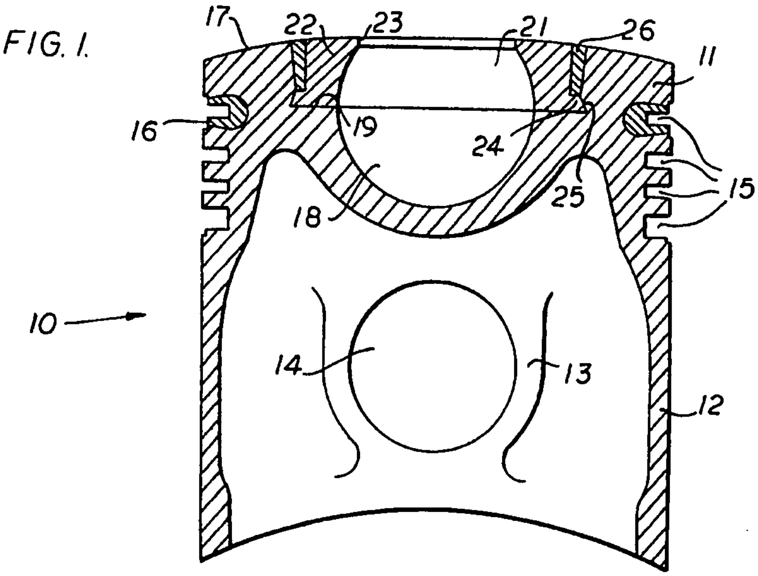

FIG. 2.

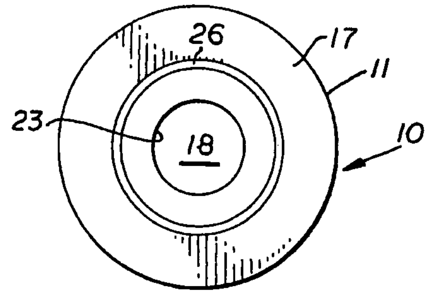

FIG. 3.